Carbon Nanotube and Nano wires

Outlines:

1. Introduction of Carbon nanotube , Nano wires
2. Different structure of CNTs
3. Properties of CNTs
4. Applications

Prerequisite/Recapitulations

Knowledge of Nanomaterials and their properties

Objectives

After the completion of this lecture, you will be able to:

1. Explain the carbon nano tubes
2. Explain the carbon nanowires
3. Understand the applications of carbon nano materials

Introduction

Definition of Nanotechnology

"*Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications.*"

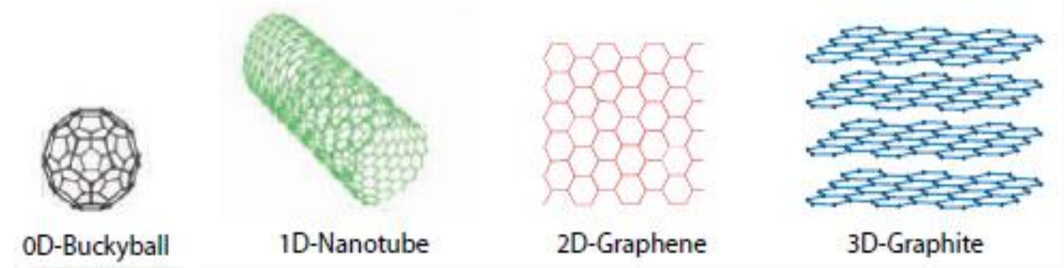
"*Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.*"

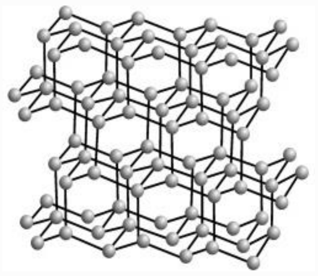
1 nanometer =
1×10^{-9} meter
1×10^{-3} µm
3.281×10^{-9} feet
39.37×10^{-9} inches

Introduction

Carbon

Carbon is a light, simple element: Its atoms contain just six electrons, two of them being core (1s) electrons and the remaining four (2sp) available for bonding with other atoms. The details of the environment in which the atoms come together (pressure, temperature, etc.) determine the types of bonds. For example, we are very familiar with the two very different bulk forms (allotropes) of carbon—that is, graphite and diamond that result from different types of bonds.

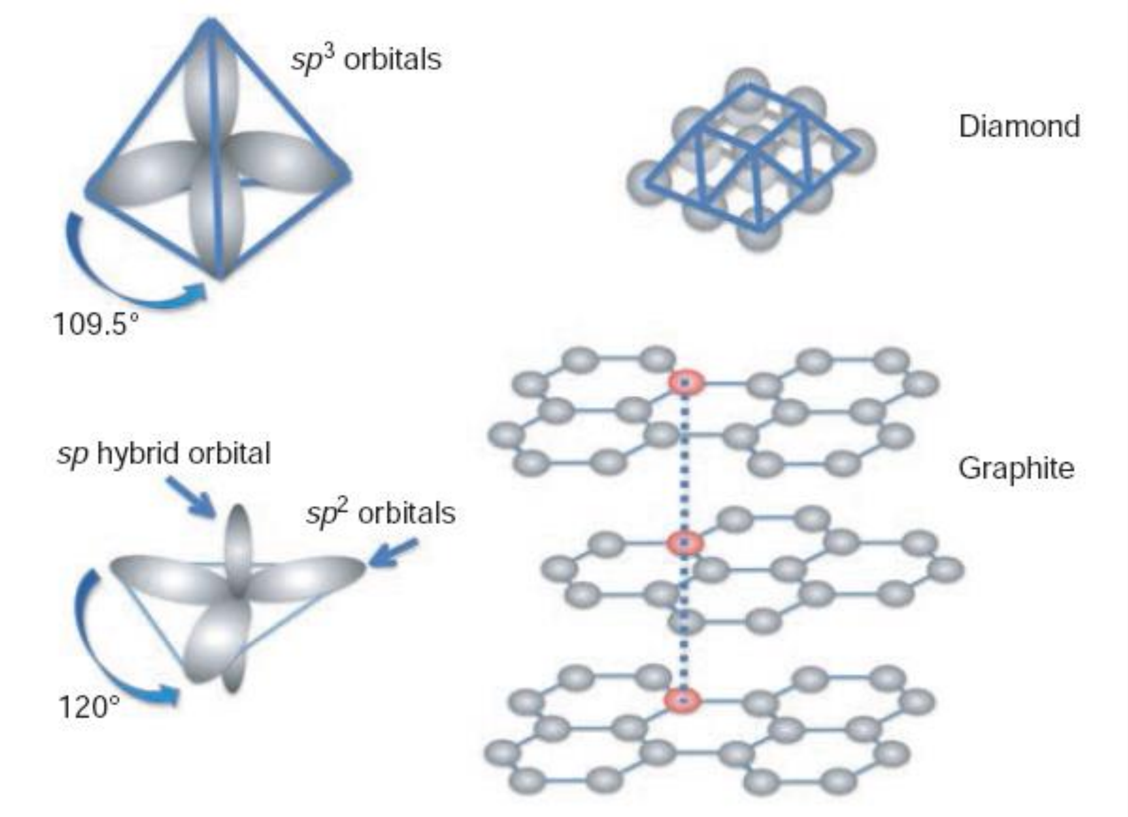




3D-Diamond

Carbon

The bonding in diamond and graphite and why they adopt their particular crystal structures is illustrated in Fig. There are four electrons in each carbon atom that produce bonding with nearest neighbors and in diamond (top) the charge distribution associated with these electrons forms a tetrahedral structure (sp3 orbitals) around each atom. The atoms thus come together in a tetrahedral arrangement. In graphite (bottom) the bonding electrons form a charge distribution of three equally spaced lobes in a plane (sp3 orbitals) with the charge distribution of the fourth being out of the plane (sp hybrid orbital). In graphite the carbon atoms are thus strongly bonded in a hexagonal arrangement in sheets with weak bonding between the sheets.



In the case of diamond, the four bonding electrons produce a tetrahedral charge distribution around each atom and so the atoms come together along these mutual bonds forming a tetrahedral arrangement. The bonds (covalent σ bonds) are strong, giving diamond its extreme hardness.

Carbon

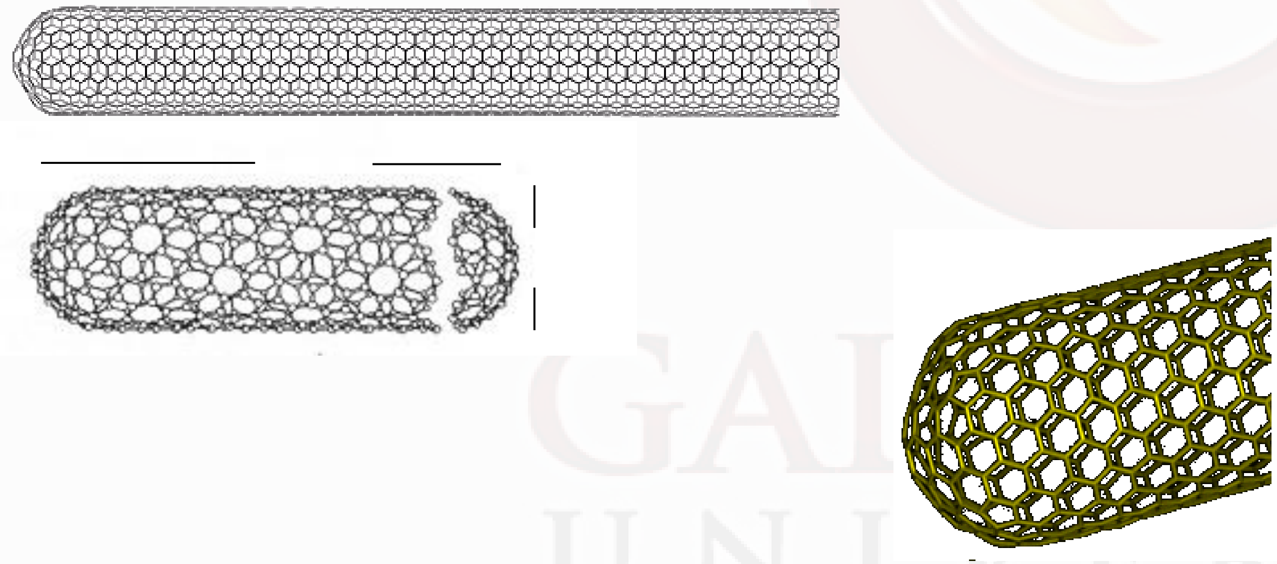
Since all the electrons are involved with bonding, they don’t interact with light, thereby making diamond a good insulator and transparent though impurities and defects can give it an intrinsic color.

In the case of graphite the charge associated with the bonding electrons forms three equally spaced lobes in a plane with the remaining bonding electron charge distributed out of the plane. In this configuration the bonding electrons form a strong hexagonal network of bonds with other carbon atoms where the in-plane bonding is even stronger then diamond. The planes, however, interact weakly (by van der Waals bonding) and can slip relatively easily with respect to each other. This gives graphite its apparent softness and lubricant quality. The remaining electrons whose charge is distributed out of the plane form a band of free electrons as in a metal, making graphite an electrical conductor.

Carbon Nano-Tubes (CNTs)

Carbon nanotubes or CNTs are a class of 1D material formed by sheets of Graphene rolled into hollow tubes of small (0.5–5nm) diameter. They were first discovered by Sumio Ijimain 1991.

CNT can be classified as single-walled CNT (SWCNT) or multiwalled CNT (MWCNT). A multiwall carbon nanotube consists of several concentric tubes of Graphene nested inside each other.



Shape and structure of Carbon nanotube (SWNT).

Carbon nanotubes are often closed at one or both ends by a hemisphere of fullerene. Figure 9 shows the structure of a tube formed by rolling the graphite sheet about an axis parallel to C-C bonds. A single-walled nanotube (SWNT) can have a diameter of 2 nm and a length of 100 pm, making it effectively a one dimensional structure called a nanowire.

Carbon NanoTubes

Fabrication: Carbon nanotubes can be made by laser evaporation, carbon arc methods, and chemical vapor deposition. There are a variety of structures of carbon nanotubes, and these various structures have different properties. Although carbon nanotubes are not actually made by rolling graphite sheets, it is possible to explain the different structures by consideration of the way graphite sheets might be rolled into tubes. A nanotube can be formed when a graphite sheet is rolled up about the axis T shown in Fig.. The C_h, vector is called the circumferential vector, and it is at right angles to T.

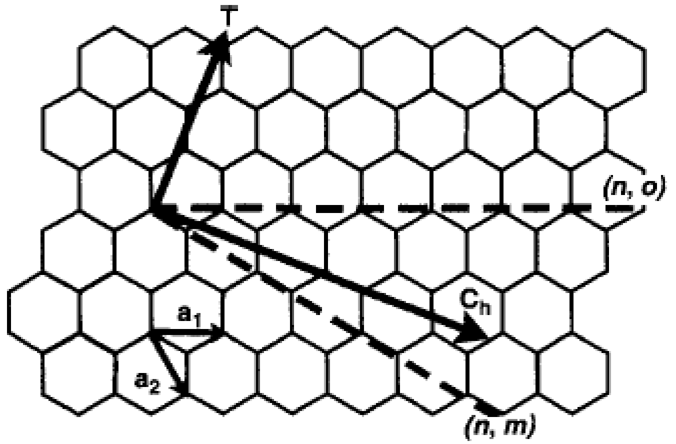


Figure . Graphite sheet showing the basis vectors *a*, and ***a2*** of the two-dimensional unit cell, the axis vector *T* about which the sheet is rolled to generate the armchair structure nanotube, and the circumferential vector $\boldsymbol{C_h}$ at right angles to *T*. Other orientations of T on the sheet generate the zigzag and chiral structures.

Carbon NanoTubes

Three examples of nanotube structures constructed by rolling the graphite sheet about the T vector having different orientations in the graphite sheet are shown in Fig. 10. When Tis parallel to the C-C bonds of the carbon hexagons, the structure shown in Fig. (a) is obtained, and it is referred to as the "armchair" structure. The tubes sketched in Figs. (b) and (C) , referred to respectively as the zigzag and the chiral structures, are formed by rolling about a T vector having different orientations in the graphite plane, but not parallel to C-C bonds. Looking down the tube of the chiral structure, one would see a spiraling row of carbon atoms. Generally nanotubes are closed at both ends, which involves the introduction of a pentagonal topological arrangement on each end of the cylinder. The tubes are essentially cylinders with each end attached to half of a large fullerene like structure.

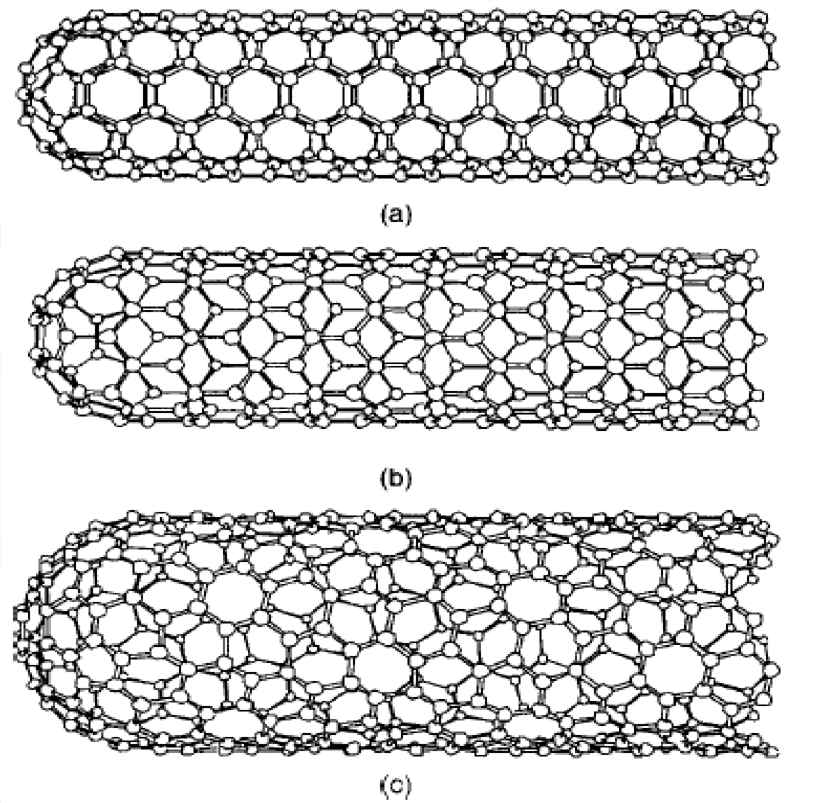


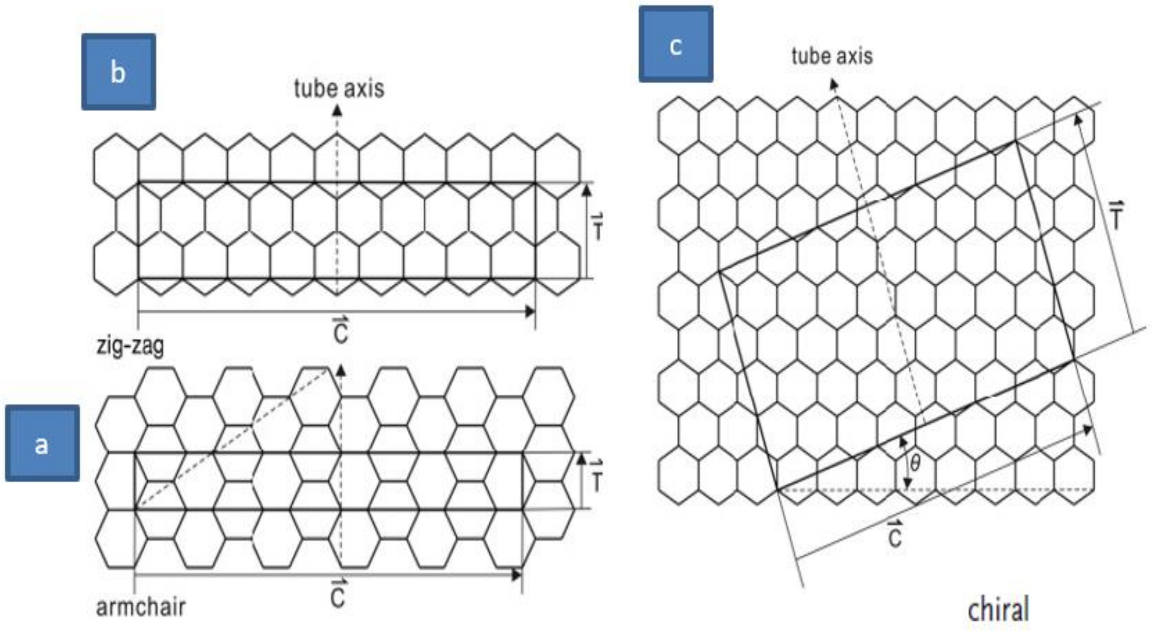
Figure: Illustration of some possible structures of carbon nanotubes, depending on how Graphite sheets are rolled: (a) armchair structure; (b) zigzag structure; (c) chiral structure.

Carbon Nanomaterials

Chirality of CNT:

Armchair carbon nanotubes (a)- In comparison to the zig - zag tubes, the Graphene sheet is turned by 30° before rolling up. The perfect boundary is an edge consisting of the sides of the last row of six -membered rings. It is good conductor.

Chiral carbon nanotubes (c)- If the angle of turning the Graphene layer before rolling up is between 0 ° and 30, chiral nanotubes are obtained. They are characterized by a line in parallel with the unity vector a1 that spirals up around the tube. Consequently two enantiomeric forms exist for these species. It is a semiconductor.



Zigzag carbon nanotubes (b)- The Graphene layer is rolled up in a way to make the ideal ends of an open tube be a zigzagged edge.

Structure related properties of nano tubes

Electrical properties:

1. Chirality of carbon changes the electrical conductivity
2. Change in conductivity from Metallic to semiconducting by insertion of pentagons and heptagons in SWNT.
3. Band gap variation with doping
4. Resistance is independent of tube length

Optical activity- The optical activity (to rotate polarized light)of chiral nanotubes disappears if the nanotubes become larger

Thermal property-

1. A distinct anisotropic thermal behaviour
2. Along the axis have high thermal conductivity
3. Quantization effects are much pronounced with, 2 nm diameter of CNT

Mechanical property-

1. CNTs have a very large Young modulus (elastic modulus- measure of stiffness)in their axial direction.
2. The nanotube as a whole is very flexible because of the great length.
3. Therefore, these compounds are potentially suitable for applications in composite materials that need anisotropic properties.

Anisotropy is the **property** of substances to exhibit variations in physical **properties** along different molecular axes. It is seen in crystals, liquid crystals and, less commonly, in liquids.

Applications of Carbon Nano-Tubes (CNTs)

- CNT composites used for electrostatically applying paints to the car components
- They can form transparent, conducting and flexible polymer composite
- Used in field emission device
- Used in tips of atomic force microscopy
- CNT with higher charge carrier mobility (20000 cm2 / V s) finds application in transistors, replacing the metal oxides
- Hydrogen storage material
- Precise mass and charge measurements (Addition of single atom or charge to CNT is detected by measuring the change in resonant frequency)
- Large non linear absorption of Light(NLO material)
- Used in optical switches
- In Lithium ion batteries: N-doped CNT show good Li+ ion storage capacity than normal graphite
- Sensors: N doped MWNT shows fast response (milliseconds) to toxic gases and organic solvents
- In field effect transistors

Questions

1. **Explain the structure of carbon**
2. **Describe the CNTs**
3. **What is carbon nano wires**
4. **What are the the different applications of CNTs?**
5. **Describe the properties of CNTs**

References

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